Technology and Behavior

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Published in:
User Behavior and Technology Development

Chapter 10

TECHNOLOGY AND BEHAVIOR:

The Case of Passenger Transport

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1. INTRODUCTION

Different policy strategies may be used to decrease the adverse environmental effects of motorized transport. *Technical innovations*, such as catalytic converters, engine efficiency improvements, or low-noise road surfaces, may lower the emissions, energy use, or noise production caused by passenger transport. *Behavioral measures*, on the other hand, aim to change environmentally relevant decisions and behaviors of transport consumers, such as the type choice when purchasing a car, the transport mode choice, or the driving speed.

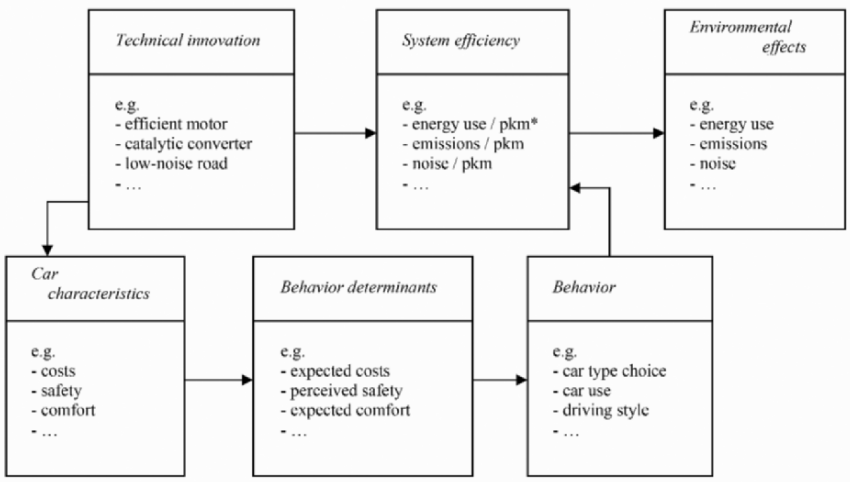
Despite obvious complexities in predicting the effects of such policy measures, assessments of the environmental potential are available for a variety of improvement options and impact categories. For instance, Bouwman & Moll (2000) and Moomaw & Moreira (2001) review the energy use reduction potential of various, mainly technical improvement options in passenger transport. Cavalini, Hendrickx & Rooijers (1995, 1996) estimate the energy use and CO_2 emission reduction potential of several behavioral policy measures. Dings (1996) and Nijland (1997) review the emission and noise reduction potential of various (mainly technical) measures.

Such assessments are usually based on *ceteris paribus* assumptions regarding other relevant factors. When assessing the effects of technical innovations, behavioral variables (e.g. total transport demand) are assumed

P.-P. Verbeek and A. Slob (eds.), User Behavior and Technology Development: Shaping Sustainable Relations Between Consumers and Technologies, 95-106.

to be constant or to follow some predefined autonomous trend. In other words, technology (T) and behavior (B) are considered as independent. However, in reality technology and behavior often interact. For instance, vehicle or infrastructural innovations aimed at increasing the efficiency of the transport system may also (inadvertently) affect environmentally relevant behaviors (T → B interaction). Or, vice versa, policy campaigns aimed at changing the behavior of transport consumers may also influence key decisions of technology designers or producers (B → T interaction). This chapter focuses on the first type of interaction (T → B). We present a conceptual model that enables us to systematically identify and analyze possible T → B interactions. We use the model to analyze three environmentally relevant decisions and behaviors of transport consumers: (a) type choice when purchasing a car; (b) transport mode choice; and (c) speed choice. On the basis of recent research on the determinants of these behaviors, we analyze how these determinants may be affected by technological innovations, and we assess how this would affect the environmental impact of the innovation. The chapter ends with general conclusions and an outline of a research agenda based on our approach.

Figure 1: Conceptual model of T → B interactions



* *pkm = passenger kilometer*

2. CONCEPTUAL MODEL

Figure 10-1 presents a conceptual model of T → B interactions. Technical innovations, such as an increase in motor efficiency, a catalytic converter, or a low-noise road surface, are aimed at improving the average system efficiency, i.e. to lower the negative environmental effects (the costs) per functional unit produced (the benefits). Costs may refer to various impact categories, such as energy use, the emission of harmful substances, or noise production, whereas benefits are usually expressed in passenger kilometers (pkm). Increases in system efficiency due to technical innovations will lower the overall impact of mobility, assuming *ceteris paribus* with regard to other relevant system parameters (e.g. other vehicle fleet characteristics), the total travel demand, and the modal split. This *intended* effect of technological innovations is shown in the upper route of Figure 10-1.

The possibility of T → B interactions is represented by the lower route in the figure. The introduction of technical innovations may affect various car characteristics, such as purchase price, fuel costs per km driven, safety level, or degree of comfort when driving (left-most lower box). Such changes may influence environmentally relevant behaviors, such as type choice, travel mode, or driving style (right-most lower box). To predict whether specific changes in car characteristics will affect mobility decisions and behaviors, we need to understand the psychological processes underlying such decisions (middle lower box). Numerous models of the psychological processes underlying mobility behavior have been proposed. For instance, decision theoretical models, like Multi Attribute Utility Theory (e.g. Von Winterfeldt & Edwards, 1986) have been used to analyze car purchase decisions (cf. Van Oijen, 1996). "Means-end chain" models (e.g. Gutman, 1997), originally developed by consumer and marketing psychologists, have been used to analyze the transport mode choices of commuters (cf. Breemhaar, Van Gool, Ester & Midden, 1995). Attitude theories, like the Theory of Planned Behavior (Ajzen, 1991), and various models based on Schwartz's (1977) Norm Activation Theory, were used to describe and explain travel behavior and travel mode choices; for a recent review of this line of studies, see Harland (2001). Travel mode choices have also been analyzed and studied from a social dilemma perspective; see, e.g. Garvill (1999), Van Lange (2000). It is unlikely that one particular type of model is appropriate for all mobility-related decisions and behaviors; the psychological processes that underlie infrequent decisions with important, long-term consequences (e.g. purchasing a new car) may differ considerably from, for instance, highly repetitive, habit-driven types of behavior (e.g. speed choice on a particular road). A detailed discussion of the various mobility behavior models proposed in the literature, and of the extent to which they are appropriate for different types of behavior, is beyond the scope of this chapter.

A basic notion all models appear to share is that the available choice options — for instance, cars one may purchase, or travel modes available for making a particular trip — are evaluated in terms of a limited set of "value dimensions" (or "decision attributes", "goals", "needs", "costs and benefits", "individual outcomes", "utilitarian consequences", or whatever label is used to indicate a set of evaluative aspects). Empirical studies, discussed in the next sections, have shown that aspects like expected travel time, perceived safety, reliability, flexibility, and expected costs play a key role in many mobility-related decisions. Innovations that affect these factors (or are expected to do so) are likely to result in behavioral changes: for example, changes in expected costs or in perceived safety may affect car type preferences; changes in expected fuel costs or travel time may alter transport mode choices; and changes in perceived comfort may influence driving style. In turn, such behavior changes may affect relevant efficiency parameters and, consequently, the environmental impact of the innovation. For instance, changes in car fleet composition, in modal split, or in mean driving style may affect energy use, emissions, and noise. In sum, environmentally-motivated technical innovations aim to increase system efficiency parameters and to decrease the total environmental impact. In practice, however, such innovations may also have behavioral side effects that alter the intended effects.

The model in Figure 10-1 constitutes a general and simplified representation of the complex processes that determine the environmental impacts of mobility. It needs to be elaborated to analyze the effects of a specific innovation. The crucial point, however, is that to recognize T → B interactions and to assess their effects, we need: (a) to identify environmentally relevant behaviors, (b) to understand how changes in these behaviors affect environmental impacts, (c) to know the main determinants of these behaviors, and (d) to understand if and how the technical innovation studied affects these determinants.

A comprehensive description of environmentally relevant behaviors and their relation to system efficiency parameters is beyond the scope of this chapter (cf. Cavalini, Hendrickx & Rooijers, 1993). To illustrate our approach, we will focus on the three examples in the right-most lower box of Figure 10-1: car type choice, car use, and driving style.

3. CAR TYPE CHOICE

If a technical innovation affects important determinants of car type choices, this will either accelerate (if the innovation makes a car more attractive) or decelerate (if the innovation makes it less attractive) the implementation of the innovation. As a consequence, the innovation's aggregate environmental benefits will either be reinforced (if the implementation is accelerated) or weakened (if it is delayed).

Determinants of car type choice have been studied by, e.g. Van Oijen (1996) and Hagreis (1996). Based on the scientific literature, popular car magazines, advertising materials, and interviews with car dealers, Van Oijen identified 26 car characteristics that affect car type choice. In an interview study, the relative importance of these attributes for business drivers with a leased car was assessed. The 26 characteristics could be meaningfully categorized into nine main factors. The average importance of the factors, as obtained by Van Oijen, is presented in the middle column of Table 10-1. Hagreis (1996) used a similar design to study car type preferences of private drivers, i.e. people who mainly use their car for private purposes like shopping, social visits, or holidays. The right column of Table 10-1 presents mean importance scores of the nine main car characteristics, as obtained by Hagreis.

Table 10-1. Relative importance of car characteristics for car type choice

car characteristic	relative importance $ (business drivers)	relative importance $ (private drivers)
Safety	0.19	0.16
Reliability	0.18	0.20
Comfort	0.15	0.10
Performance	0.12	0.07
Costs	0.10	0.17
Appearance	0.08	0.07
Functionality	0.08	0.10
After-sales (e.g. service)	0.06	0.05
Environmentally friendly	0.04	0.08

* Source: Van Oijen (1996), Hagreis (1996)

$ Higher score → characteristic more important; scores rescaled to add up to 1

Table 10-1 shows that safety, reliability, and to a lesser extent comfort, costs, and performance, appear to be the main aspects people consider in selecting a car. Innovations that — in the consumer's eyes — decrease car safety or reliability, may encounter serious implementation problems. Environmentally-motivated innovations that may evoke safety concerns include the use of lightweight materials in cars or the introduction of alternative fuels like hydrogen. Reliability concerns may drive people away from radical technological changes, such as the introduction of fuel cell cars. Characteristics like comfort or cost may be used to accelerate the implementation of an innovation. For instance, emphasizing that cruise control and low-noise tires enhance driving comfort may be a more efficient way to promote such innovations than highlighting their environmental benefits. As often, the cost aspect forms a double-edged sword. Innovations that reduce travel costs, for instance because they lower the fuel consumption per km, may be implemented relatively quickly, but they may also induce shifts in modal split (see next section). Table 10-1 also reveals that the average driver weighs costs more heavily than environmental benefits. This suggests that people will not be very willing to pay more for innovations that only reduce environmental impacts. Temporary subsidies or tax compensations, for instance on low-sulfur fuels or on hybrid cars, may be necessary to overcome financial barriers.

4. TRANSPORT MODE CHOICE

The environmental effects of transport mode choices are complex. The relative efficiency of different transport modes varies across impact categories, but also depends on trip-specific factors, e.g. the particular vehicle used, the occupancy rate, and the trip length. For a comparison of the energy and emissions factors associated with different modes of passenger transport in the Netherlands, see Van den Brink & Van Wee (1997). In general, traveling by car or airplane has a larger environmental impact than traveling by train, bus, or metro; non-motorized transport (cycling and walking) clearly has the lowest impact.

The determinants of transport mode choice have been studied by e.g. Steg (1996) and Tertoolen, Van Kreveld & Verstraten (1998). Speed and independence ("leave any time I want, get anywhere I want") are important determinants of transport mode choice. Other relevant factors are comfort, costs, social safety, physical safety, health, environmental friendliness, and luggage capacity. Each of these determinants may serve as a mediator of T → B interactions. For instance, innovations that decrease the perceived level of independence (e.g. electric cars that require frequent recharging) may be difficult to implement (see previous section). However, once implemented, such innovations may bring about a shift in modal split away from the car, which augments the innovation's environmental benefits (assuming the shift is towards transport modes with lower impacts). Technical innovations that increase automobile fuel efficiency also reduce driving costs, which may increase car use, either because the total mobility demand increases or because the modal split shifts towards car use. This effect is probably not very large, as both studies cited above indicate that for the average driver costs are not a main determinant of transport mode choice. Studies on fuel price elasticity confirm this finding: fuel price increases tend to have relatively small effects on car mileage (price elasticity of approximately –0.2/–0.3, see Pronk & Blok, 1991). Another possible mediator of T → B interactions is the extent to which (potential) drivers perceive car use as harmful to the environment. It is conceivable that if environmental concerns play a significant role in transport mode choice, people may curtail their car use because of such concerns. If so, innovations that make cars more "environmentally friendly" may backfire if they induce people to lift the self-imposed restrictions. Unfortunately, the extent to which environmental concerns play a role in transport mode choices is unclear. The studies cited above yield conflicting findings; other empirical studies (reviewed in Steg, 1999) show that the correlation between environmental concerns and car use tends to be rather weak. Steg (1999), for instance, obtained a correlation value of –0.11. Nevertheless, technology is sometimes used as an excuse for unwanted behavior, for instance when people justify excessive car use by pointing out that their car has a catalytic converter or runs on "clean" fuel.

5. DRIVING STYLE

Driving behavior affects the environmental impacts of car use. Average fuel consumption, the emission of harmful substances, and noise production decrease if drivers select an adequate cruising speed, avoid extreme acceleration, and anticipate oncoming traffic situations (e.g. Ericsson, 1999; Van der Voort, 2001). On the basis of a literature review, Orlemans (1997) identified a large number of factors that possibly influence driving style. Individual characteristics, such as age and gender, are related to driving style: young drivers and/or male drivers tend to drive more aggressively than older and/or female drivers. Infrastructural characteristics, such as lane width and road surface roughness, also affect speed choice (Martens, Comte & Kaptein, 1997). Orlemans mentions various car characteristics that may be related to driving behavior (e.g. top speed, motor power, car age, car size and type, brand, comfort, fuel type, fuel use), but relevant research is lacking.

Side effects of a technical innovation on driving style determinants may alter the innovation's overall impact. If fuel cost considerations affect the way people drive, then increasing a car's fuel efficiency may result in more aggressive driving. T → B interactions on driving style may also be mediated by driving comfort. Driving comfort tends to decrease at higher speeds, for instance because of the noise level inside the car, the effects of road surface irregularities, and the mental effort required for driving, all tend to increase with driving speed. Such comfort-related factors may be a reason for drivers to restrict their speeds. If this is the case, then technologies that increase driver comfort, such as low-noise tires, silent road surfaces, or cruise control, may evoke higher driving speeds. And if environmental concerns affect the way people drive — which, to our knowledge, has not been studied yet — then innovations that make cars (appear) more "environmentally friendly" may tempt people to alleviate self-imposed restrictions regarding, e.g. speed choice. However, the lack of knowledge about the determinants of driving style prohibits firm predictions about the effects of technical innovations on driving behavior.

6. CONCLUSIONS

The conceptual model of T → B interactions in Figure 10-1 offers a useful methodology for identifying possible behavioral side effects of technical innovations. However, the driving style example particularly shows that, of the four steps necessary to identify T → B interactions (see above), identifying the behavioral determinants (step c) is the hardest one. For many behaviors, insight into the underlying mechanisms and processes is still rudimentary. With regard to future research we therefore expect that studies aimed at clarifying the determinants of environmentally relevant behaviors will have the largest added value.

In theory, behavioral side effects of new technologies may increase their environmental effects. In fact, as illustrated in the section on car type choice, a behavioral side effect may be used intentionally to reinforce the primary effects of an innovation. However, our examples suggest that many T → B interactions will be counterproductive and will result in what economists call *rebound effects* (cf. Binswanger, 2001). Timely awareness of such effects may prevent unrealistic optimism and overestimation of the environmental benefits of technological progress. Particularly in the transport domain, environmental policy targets often needed to be "adjusted" because the yield of technical improvements turned out to be less than expected. Awareness of possible T → B interactions may also create opportunities, e.g. for car designers or policy makers, to avoid or minimize undesirable side effects.

A four-step procedure for identifying possible T → B interactions was presented in section 2. Case-specific information on if and how a new technology will affect relevant behaviors may be collected in various ways. Sometimes literature-based analyses may provide sufficient information. It may also be necessary to conduct interview studies in which relevant consumer groups are asked how the new technology would affect their behaviors. In addition, small-scale pilot projects may be conducted in which the behavior of new technology users is systematically monitored. If such studies indicate that major behavioral side effects are possible, the introduction of the innovation should be accompanied by large-scale evaluation studies, in which both the critical behavior and the targeted environmental parameters are examined.

While consumer costs do constitute an important mediator for T → B interactions (T → Costs → B, see above), costs are by no means the only route through which T → B interactions may occur. Our examples suggest that perceived safety, trip speed, reliability, comfort, and environmental friendliness may also mediate T → B interactions. Therefore, when studying T → B interactions, focusing solely on financial rebound effects is insufficient. Recently, Binswanger (2001) expanded the traditional economic (price-mediated) analysis of the rebound effect to include "*a rebound with respect to time …This means that the introduction of a time-saving device for the production of a service will also lead to an increase in the demand for a service*" (op. cit., page 128). The T → B interactions presented here suggest that Binswanger's quantitative modeling of time-related rebound effects, though highly valuable, only constitutes the first in a series of necessary model expansions.

7. A RESEARCH AGENDA

To conclude, we will outline a research agenda based on our approach. With regard to the information necessary to identify possible T → B interactions (see the four-step procedure indicated above), a better understanding of the psychological determinants of various mobility behaviors is most critical. The majority of studies on mobility behavior determinants have focused on travel mode choice (for recent examples, see Steg, Vlek & Slotegraaf, 2001; Hunecke, Blöbaum, Matthies & Höger, 2001). Other behaviors, such as the decision whether or not to buy a car, type choice when purchasing a car, the routing and timing of trips, and driving style, have received much less attention. This is remarkable, as some of these behaviors are highly relevant from an environmental point of view.

Therefore, studies addressing the psychological determinants of, say, car purchase decisions, type choice, and driving style should form a first priority. Such studies should preferably examine actual rather than reported preferences and behaviors, and they should aim at determining how these behaviors vary as a function of individual, car and traffic-system characteristics. For some behaviors it may be necessary to distinguish subgroups of transport consumers, differing in their sensitivity to specific behavior determinants. For instance, Table 10-1 shows that "costs" constitute a more important determinant of type choice for private drivers than for business drivers. This research line should aim at developing comprehensive models of the psychological factors and processes underlying various mobility behaviors.

A second research line should focus on actual or foreseeable technological innovations in the transport system. First, the impacts of an innovation on actual car or infrastructural characteristics should be analyzed and assessed. Next, these "innovation effects" should be related to the sets of behavioral determinants provided by the first research line. This will result in specific hypotheses about the behavioral effects of the innovation at hand. Again, it may be necesssary to specify such effects separately for subgroups of mobility consumers differing in sensitivity to behavior determinants. Such hypotheses should then be tested, either in small-scale pilot studies, or in monitoring programs that accompany the large-scale introduction of the technology (see previous section). The primary aim of this second research line is to assess the nature, the size, and the environmental effects of T → B interactions, induced by specific innovations. However, as the introduction of a new technology may present unique opportunities for conducting (field) experiments, these studies may also be useful for validating more general behavior models and theories. In this way, the two research lines proposed here may fruitfully interact.

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